Interactive comment on "A Retrospective Streamflow Ensemble Forecast for an Extreme Hydrologic Event: a Case Study of Hurricane Irene and on the Hudson River basin" *by* F. Saleh et al.

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Subject: Scenario analysis for streamflow precasting

I've read with interest the executive–style summary of a comprehensive analysis of a recent extreme flood event. The storm and flood data from the retrospective ensemble streamflow forecast using HEC-HMS model for Hurricane Irene on the Hudson River Basin are summarized in Table 1 of the Discussion Paper.

I would call the "Retrospective" analysis also a "Scenario" one for streamflow

pre–(fore)casting, even though theirs is only for one storm on one basin using one hydrologic model.

It is virtually impossible to reproduce a past storm and flood event, an example of this being their 21 different precipitation reforecast datasets. The best that one can do is to capture its salient features and plan for the next bigger ones.

In contrast to the modified Clark unit hydrograph method in the semi–distributed HEC–HMS model, I suggest for consideration a lumped, though nonlinear, rainfall excess – direct runoff module. This is typified by a variable instantaneous unit hydrograph (vIUH) model of the 1974 vintage (Ding, 1974, 2011; Jun, 1989; Stanescu and Musy, 2006).

In hindsight, the concept of a nonlinear watershed response was first captured by Childs (1958) in a study on an earlier hurricane ("Diane") on nearby basins in New England. In it, he showed a family of observed nonlinear unit hydrographs for the Naugatuck River at Thomaston in Connecticut, which was reprinted in Ding (2011, Figure 2). His illuminating diagram was available both in a conference preprint and later a journal paper. From its very beginnings, however, this, to me, visionary work seemed to have fallen off our collective radar screen.

The hindcast data in their Table 1 enable an initial calibration, for the five sub-basins, of a 2011 variety of the vIUH model. This was a product of the Manning friction law, and had only one parameter. For calibration, in addition to the rainfall–excess data, this requires only the time to the flood peak and/or its magnitude, all observed, estimated, simulated, or a combination thereof.

This nonlinear rational–type formula for peak flow prediction (Ding, 2011, Eqs. 28 and 29) is as follows:

$$Q(j_p) = 0.2c(R_E/\Delta t)^{1.4} A\Delta t \ ,$$

$$j_p = 0.5 + \frac{0.535}{c(R_E/\Delta t)^{0.4}\Delta t} \ ,$$

in which:

$Q(j_p)$ = peak flow (m^3/s),

j_p = peak time (Δt),

A = basin area (km^2),

Δt = timestep size (h); also the duration of the rainfall–excess storm,

R_E = rainfall excess (mm),

c = scale parameter ($(mm \ h^{-1})^{0.6}$).

For this Short Comment, only the short, 24-hour forecast lead–time is considered. The major assumptions made are:

- There was no distinction made between the rainfall and the rainfall–excess, i.e.

  the basin was fully saturated and the infiltration losses negligible, and

- The rainfall–excess hyetograph was uniformly distributed in time.

New Tables 1 and 2 show, respectively, the input data for and output data from a step–by–step calculation for the vIUH parameter c values and the model's peak times for five sub–basins. These peak times are longer than the "fixed" peak time of 24 h, i.e. $0.5\Delta t$, in the Discussion Paper.

The scale parameter c value of 0.059 for the Prompton River is seen more than twice the rest. Figure 2 of the Discussion Paper indicates that this is a downstream-most basin having apparently a highest imperviousness or urbanization ratio. Through the lens of the vIUH model, the Prompton River was flahier than the rest.

The 1–parameter vIUH model assumes a nonlinear storage–discharge relation of the form: $Q = c^{1.67}S^{1.67}$, where S is the water storage (mm). This is in contrast to the linear relation, $S = RQ$, in the 2–parameter Clark synthetic unit hydrograph method, where R is a storage coefficient (h). (The Clark method has a second parameter t_c, the time of concentration, e.g. Straub et al., 2000).

The vIUH scale parameter c and the Clark coefficient R can be made related to each other by equating Q in these two relations. This gives: $c = (1/R^{0.6})(1/S^{0.4})$. In a unit hydrograph, the storage S is a variable represented by a recession curve starting from a maximun "unit amount" of the rainfall excess. Further comparative analysis using, for example, the statistical moments matching method (e.g. Ding, 1974, page 63) will be productive, such as determining the amount of storage remaining at the peak time especially by the Clark method. But this is beyond the scope of this Short Statement.

Lastly, the initial parameter c value is re–calibratable (i.e. updatable) real–time from new observations using the Kalman filter, though I've had no personal experience implementing one.

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Table 1. Simulated input data for initial calibration of the vIUH model for the Hudson River Basin

Hurricane Irene on the Hudson River Basin
Storm duration $\Delta t = 48\ h$
Forecast lead–time $24\ h$

Station name USGS ID	Basin area A km^2	NARR precip–excess R_E mm	Simulated peak flow			Precip–excess intensity $R_E/\Delta t$ mm/h
			2nd m^3/s	98th m^3/s	Mean* $Q(j_p)$ m^3/s	
Saddle River at Lodi, NJ 1391500	141	143	105	200	152.5	2.979
Hackensack River at New Milford, NJ 1378500	293	143	225	442	333.5	2.979
Walkill River at Gardiner, NY 1371500	1800	106	558	1585	1071.5	2.208
Pomtpon River at Pompton Plains, NJ 1388500	329	130	490	1024	757.0	2.708
Croton River on Hudson, NY 1375000	979	126	503	1205	854.0	2.625

Source of data: Saleh et al. (2016).
∗ the average of the peak flows at 2nd and 98th percentiles.

Table 2. Initial calibrated vIUH parameter values for the Hudson River Basin

Hurricane Irene on the Hudson River Basin
$Q(j_p) = 0.2c(R_E/\Delta t)^{1.4}A\Delta t$
$j_p = 0.5 + \frac{0.535}{c(R_E/\Delta t)^{0.4}\Delta t}$

Station name USGS ID	vIUH parameter c $(mm\ h^{-1})^{0.6}$	peak time j_p Δt
Saddle River at Lodi, NJ 1391500	0.029	0.725
Hackensack River at New Milford, NJ 1378500	0.026	0.711
Walkill River at Gardiner, NY 1371500	0.020	0.768
Pomtpon River at Pompton Plains, NJ 1388500	0.059	0.593
Croton River on Hudson, NY 1375000	0.024	0.728